CS1010S Programming Methodology

Lecture 5
Data Abstraction & Debugging

12 Sep 2018

Collaboration Policy

By all means discuss

But write the solution <u>yourself</u>

Group Discussion

- Discard all code/solutions from group discussion
- Every one goes home and rewrite their own solution.
- No emailing of code allowed

Recap: Higher Order Functions

All three functions are very similar.

```
def sum_integers(a, b):
  if a > b:
    return 0
  else:
    return a +
          sum_integers(a + 1, b)
```

```
def pi_sum(a, b):
  if a > b:
    return 0
  else:
    return 1/(a*(a + 2)) +
           pi_sum(a + 4, b)
```

```
def sum_cubes(a, b):
  if a > b:
    return 0
  else:
    return cube(a) +
           sum_cubes(a + 1, b)
```

```
def <name>(a, b):
  if a > b:
    return 0
  else:
    return <term>(a) +
           <name>(<next>(a), b)
```

Recap: Higher Order Functions

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  if a > b:
    return 0
  else:
    return cube(a) +
        sum_cubes(a + 1, b)
```

```
def <name>(a, b):
  if a > b:
    return 0
  else:
    return <term>(a) +
        <name>(<next>(a), b)
```

We can abstract this common pattern

Common Abstraction

```
def sum(term, a, next, b):
  if a > b:
    return 0
  else:
    return term(a) +
           sum(term, next(a), next, b)
```

functions

Re-defining

```
def sum_integers(a, b):
    return sum(inden, a, inc, b)

def sum_cubes(a, b):
    return sum(cube, a, inc, b)

def pi_sum(a, b):
    return sum(lambda x: 1/(x*(x+2)), a
               lambda x: x+4, b)
```

Isn't sum just

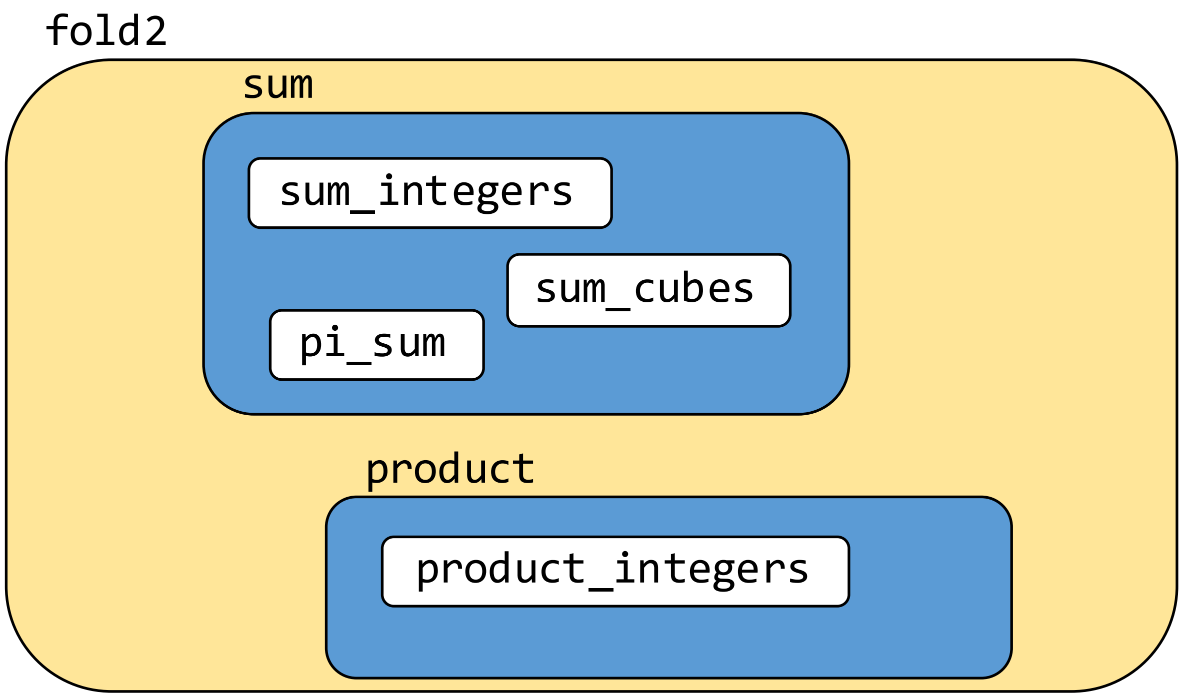
$$\sum_{a}^{b} t(x)$$

Taylor's Expansion

$$e^x = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots$$

$$e^x = 1 + \sum_{n=1}^{\infty} \frac{x^n}{n!}$$

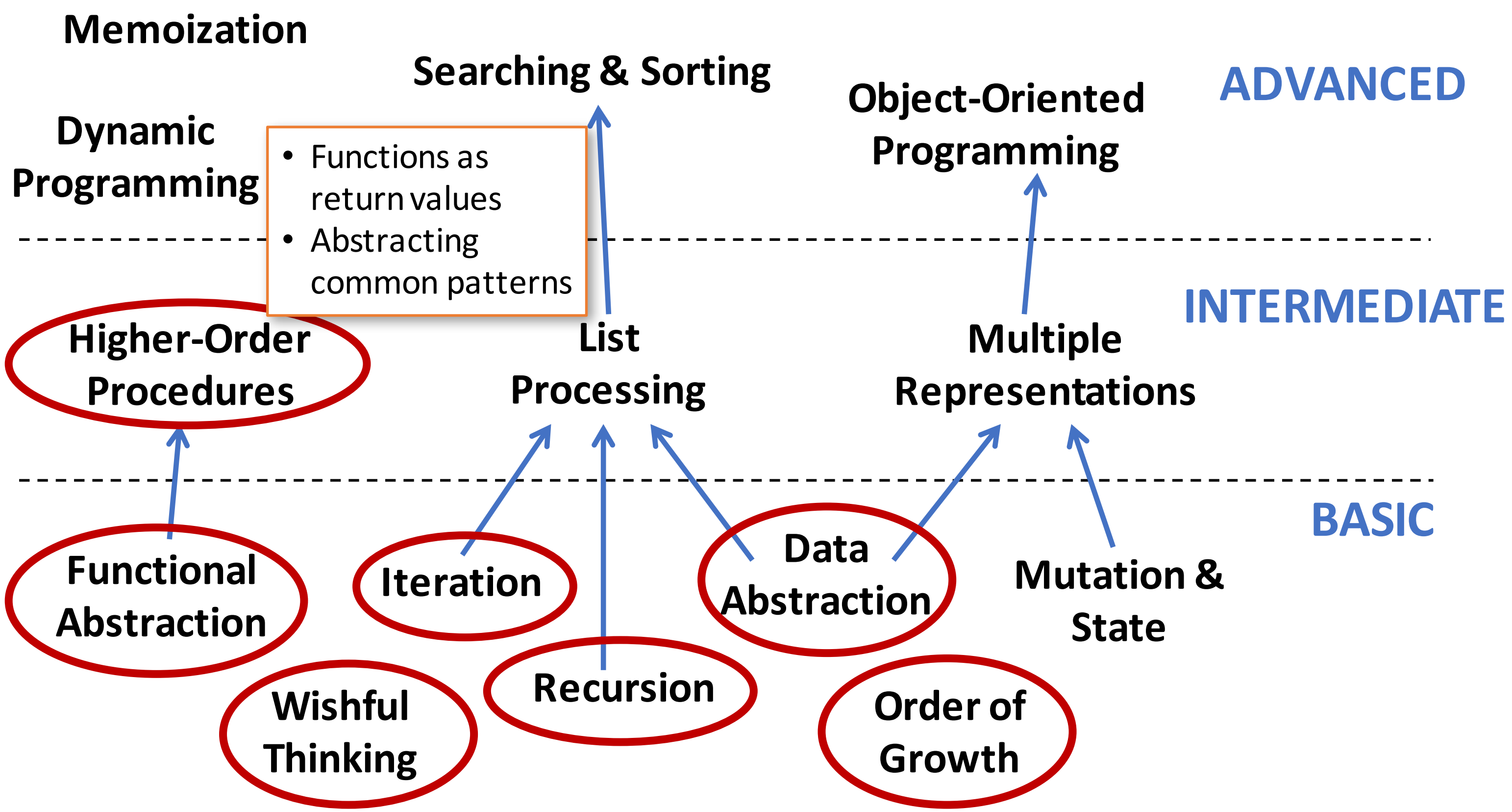
We can write a more general function to define other functions



Higher Order Functions

- Functions as input
  - Abstract common patterns
    e.g. `sum`, `fold`, `fold2`
- Function as output
  - Manipulate functions
    e.g. `deriv`, `composite`
  - Capture variables
    e.g. `adder`

CS1010S Road Map



Fundamental concepts of computer programming

So far we have only dealt with very simple data:

Numbers

(and some pictures)

However, life is complicated


AAAAHHH!!!
Why is life so Complicated??

To do anything useful, we need to model

REAL objects

Example

NUS Registrar has a record of every student

- Personal info, modules taken, grades, etc.
- Record may be a paper folder or electronic document
- Record is a compound data

Recall: Functional Abstraction

- Only need to know how a function transforms inputs to an output
- Don't need to know how it is implemented

Recall: Functional Abstraction

- Abstracts away irrelevant details, exposes what is necessary
- Separates usage from implementation
- Captures common programming patterns
- Serves as a building block for more complex functions

Key Idea

We can organize and reason about data the same way!

Data Abstraction

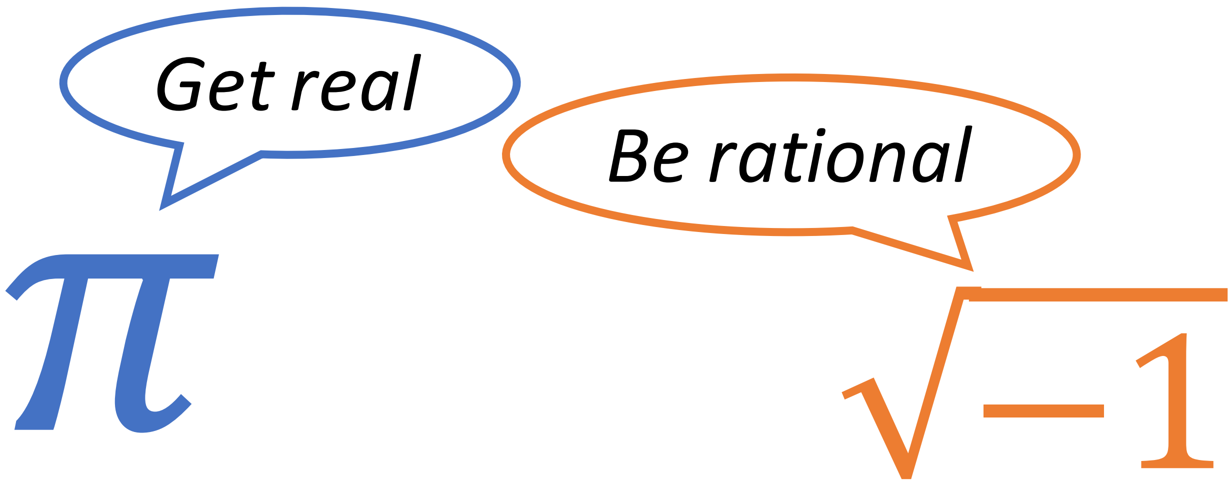
- Abstracts away irrelevant details, exposes what is necessary
- Separates usage from implementation
- Captures common programming patterns
- Serves as a building block for other compound data

Case Study

`float` is imprecise

better to work with fractions

Rational Numbers



Rational Number Package

- Rational number: $\frac{n}{d}$
  - ${}^{3}/_{5}$, ${}^{-1}/_{2}$
  - n: numerator
  - d: denominator
- Provide arithmetic operations
  - Addition
  - Subtraction
  - Multiplication, etc.

Guidelines for Creating Compound Data

- Constructors
  - To create compound data from primitive data
- Selector (Accessors)
  - To access individual components of compound data
- Predicates
  - To ask (true/false) questions about compound data
- Printers
  - To display compound data in human-readable form

Wishful Thinking

Let's wish for the following:

- `def make_rat(n, d): # constructor`
  - Returns a rational number with numerator *n*, denominator *d*
- `def numer(rat_number): # selector`
  - Returns the numerator of rat-number
- `def denom(rat_number): # selector`
  - Returns the denominator of rat-number

Arithmetic Operations

Addition:

$$\frac{n_1}{d_1} + \frac{n_2}{d_2} = \frac{n_1 d_2 + n_2 d_1}{d_1 d_2}$$

```
def add_rat(x, y):
    nx, dx = numer(x), denom(x)
    ny, dy = numer(y), denom(y)
    return make_rat(nx * dy + ny * dx, dx * dy)
```

Arithmetic Operations

Subtraction:

$$\frac{n_1}{d_1} - \frac{n_2}{d_2} = \frac{n_1 d_2 - n_2 d_1}{d_1 d_2}$$

```
def sub_rat(x, y):
    nx, dx = numer(x), denom(x)
    ny, dy = numer(y), denom(y)
    return make_rat(nx * dy - ny * dx, dx * dy)
```

Arithmetic Operations

Multiplication:

$$\frac{n_1}{d_1} \times \frac{n_2}{d_2} = \frac{n_1 n_2}{d_1 d_2}$$

```
def mul_rat(x, y):
  return make_rat(numer(x) * numer(y),
                  denom(x) * denom(y))
```

Arithmetic Operations

Division:

$$\frac{n_1}{d_1} \div \frac{n_2}{d_2} = \frac{n_1 d_2}{d_1 n_2}$$

```
def div_rat(x, y):
    return make_rat(numer(x) * denom(y),
                    denom(x) * numer(y))
```

Predicates

Equality:

$$\frac{n_1}{d_1} = \frac{n_2}{d_2} \leftrightarrow n_1 d_2 = n_2 d_1$$

```
def equal_rat(x, y):
    return numer(x) * denom(y) == numer(y) * denom(x)
```

Printers

Displaying:

```
def print_rat(rat):
    print(f'{numer(rat)}/{denom(rat)})

print_rat(make_rat(1, 2)) → 1/2
```

Recall

- We assumed the existence of
  - `make_rat(n, d)`
  - `numer(rat_number)`
  - `denom(rat_number)`
- From which we defined new operations
  - `add_rat`, `sub_rat`, `mul_rat`, `div_rat`, `equal_rat`, `print_rat`
- Now what about our assumptions?
  - `make_rat`, `numer`, `denom`

Implementing rats

We can use a Python primitive called a tuple to "bind" data together

```
foo = (x, y) # creates a tuple out of
             # x and y
foo[0]   # return 1st component of foo
foo[1]   # return 2nd component of foo
```

Tuple

```
x = (1, 2)
x → (1, 2)

x[0] → 1
x[1] → 2

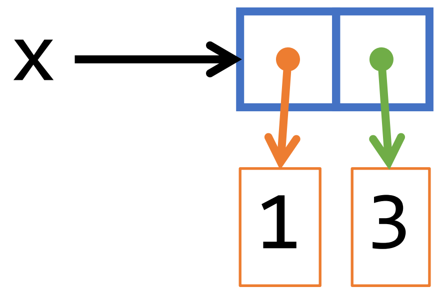
y = (3, 4)
z = (x, y) # A tuple of tuples

z[0][0] → 1
z[1][1] → 4
```

Box-and-pointer notation

A way to visualize tuples

```
x = (1, 3)
```



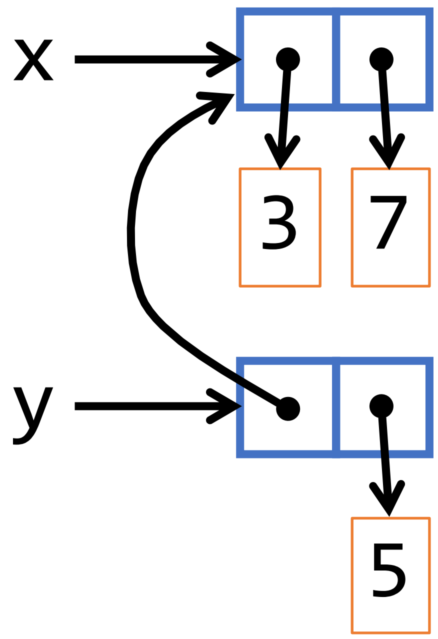
- Variables x points to tuple
- Left arrow is `[0]`
- Right arrow is `[1]`
- Numbers are outside the tuple, not inside

Box-and-pointer notation

```
x = (3, 7)
x → (3, 7)

y = (x, 5)
y → ((3, 7), 5)

y[0][0] → 3
y[0][1] → 7
```



More on Tuples

A tuple is a common structure:

```
bar = (1, 2)
bat = (3, 4)
foo = bar + bat  # creates a new tuple
foo → (1, 2, 3, 4)

foo = (bar, bat)
foo → ((1, 2), (3, 4))
```

`()` is the empty tuple.

Recall String Slicing?

```
s[start:stop:step]
```

non-inclusive

```
>>> s = 'abcdef'
>>> s[0:2]
'ab'
>>> s[1:2]
'b'
>>> s[:2]
'ab'
```

```
>>> s[1:5:3]
'be'
>>> s[::2]
'ace'
```

Slicing returns a new string

Tuple Selectors

`foo`	returns the tuple foo
`foo[0]`	returns 1^{st} element of foo
`foo[1:]`	returns tail of foo (rest of foo without 1^{st} element)
`foo[a:b]`	returns tuple consisting of $a+1^{th}$ to b^{th} element of foo
`foo[a:b:c]`	returns tuple consisting of $a+1^{th}$ to b^{th} element of foo, in steps of c
`foo[-1]`	returns the last element of foo
`len(foo)`	returns the number of elements in foo

Examples

```
x = (1, 2, 3, 4)
x[0]      → 1
x[1:]     → (2, 3, 4)
x[0:]     → (1, 2, 3, 4)
x[1:3]    → (2, 3)
x[1:2]    → (2,) # not the same as (2)
x[1]      → 2
x[-1]     → 4
x[:3:2]   → (1, 3)
len(x)    → 4 # length of tuple
```

Iterating over tuples

```
x = (4, 2, 1, 3)

count = 0
for i in x:
    print(i)
    count = count + i
print(count)
```

```
4
2
1
3
10
```

Rational Number

We can complete our rational number package by defining:

```
def make-rat(n, d):
   return (n, d)

def numer(rat):
   return rat[0]

def denom(rat):
   return rat[1]
```

Using Rational Number

```
>>> one_half = make_rat(1, 2)
>>> print_rat(one_half)
1/2

>>> one_third = make_rat(1, 3)
>>> print_rat(one_third)
1/3

>>> print_rat(add_rat(one_half, one_third))
5/6

>>> print-rat(mul_rat(one_half, one_third))
1/6

>>> print-rat(add_rat(one_third, one_third))
6/9
```

Yikes! Why not 2/3?

Improvement

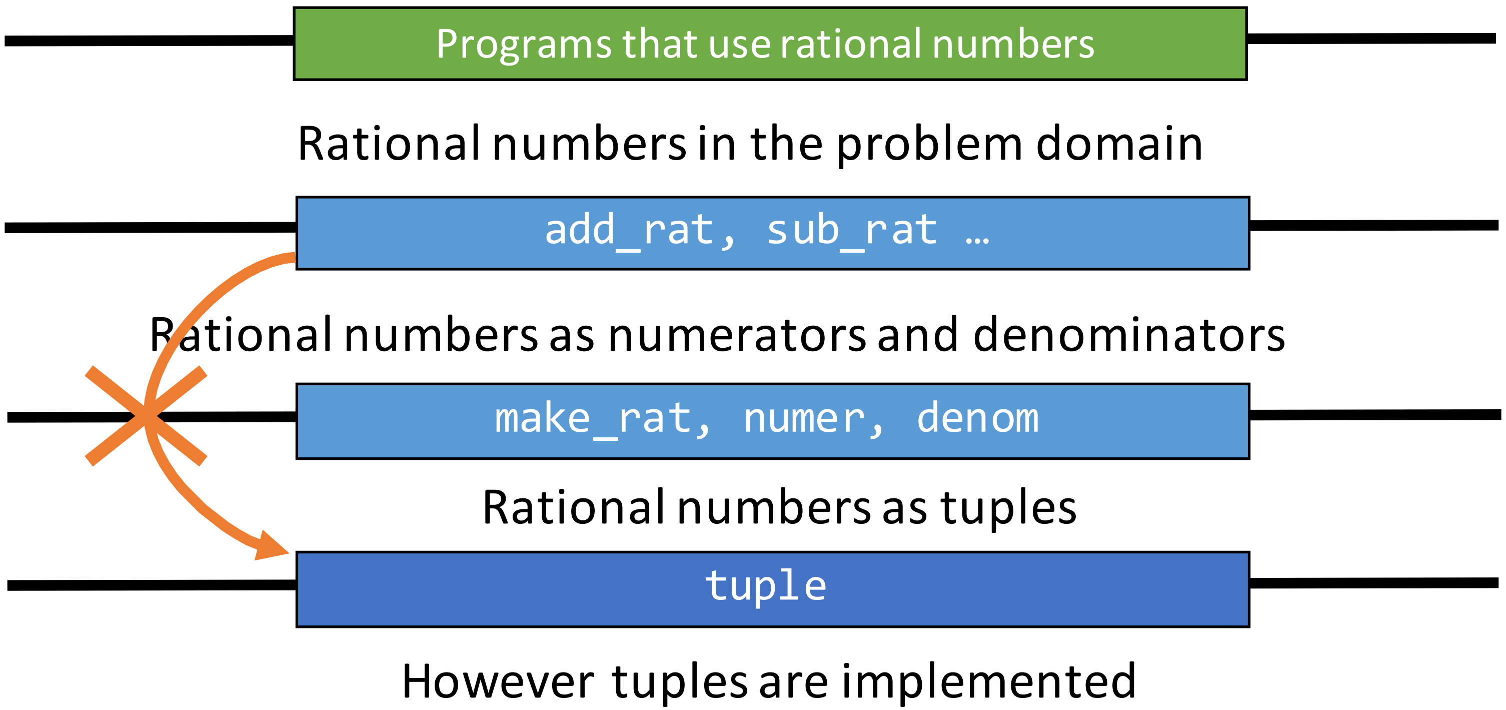
We can “reduce to lowest terms” by modifying `make_rat`

$$\frac{kp}{kq} = \frac{p}{q} \text{ where } k \text{ is } \mathrm{gcd}(p, q)$$

```
from fractions import gcd

def make_rat(n, d):  # version 2
    g = gcd(n, d)
    return (n//g, d//g)
```

Abstraction Barrier



At each level, use only functions available at that interface, not below it.

Equality

What does equality mean?

Two possibilities (usually)

1. Identity
   - This means the SAME object (reference in memory)
   - In Python, we use `is` to test this.

Two possibilities (usually)

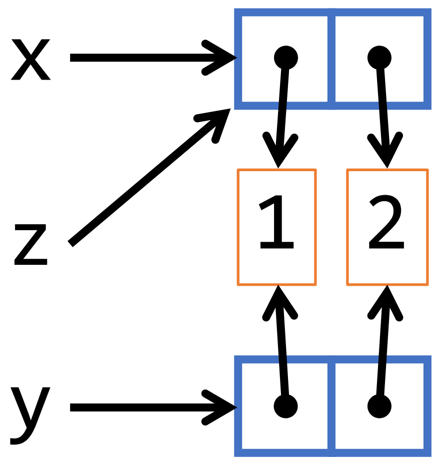
2. Equivalence
   - This means two objects are equivalence (of the same value) even if they are not the same object
   - In Python, we use == to test this.

Identity != Equivalence

Equality

`is` returns `True` if the two objects are the same object
`==` returns `True` if the two objects are equivalent

```
x = (1, 2)
y = (1, 2)
x is y → False
x == y → True
z = x
z is x → True
z is y → False
z == y → True
```



Caution with is

`is` cannot be used to compare numbers reliably

```
>>> 3 is 3
True

>>> 3.000 is 3
False
```

Equality

The predicate == returns True if the two object have the same contents

- works for numbers, strings and tuples

```
>>> ('apple', 1, 2, 3) == ('apple', 1, 2, 3)
True
>>> ('apple', 1, 2, 3) is ('apple', 1, 2, 3)
False
>>> ('apple', 1, 2, 3) == ('apple', (1, 2), 3)
False
```

To add to confusion: ==

```
>>> ('apple', 1, 2, 3) == ('apple', (1), 2, 3)
True
>>> ('apple', 1, 2, 3) == ('apple', (1,), 2, 3)
False

>>> t = (1)
>>> t
1

>>> s = (1,)
>>> s
(1,)
```

Moral of the story

Use `==` and `is` carefully, to save yourself grief.

Debugging

Humans make mistakes

You are only human

Therefore, you will make mistakes

Debugging

- Means to remove errors ("bugs") from a program.
- After debugging, the program is not necessarily error-free.
  - It just means that whatever errors remain are harder to find.
  - This is especially true for large applications.

Common Types of Errors

- Omitting return statement

```
def square(x):
    x * x        # no error msg!
```

- Incompatible types

```
x = 5
def square(x):
    return x * x
x + square
```

- Incorrect # args

```
square(3,5)
```

Common Types of Errors

- Syntax

```
def proc(100)
    do_stuff()
        more()
```

- Arithmetic error

```
x = 3
y = 0
x/y
```

- Undeclared variables

```
x = 2
x + k
```

Common Types of Errors

- Infinite loop (from bad inputs)

```
def factorial(n):
  if n == 0:
    return 1
  else:
    return n * factorial(n-1)

fact(2.1)
fact(-1)
```

Common Types of Errors

- Infinite loop (from not decrementing)

```
def fact_iter(n):
    counter, result = n, 1
    while counter!= 0:
        result *= counter
    return result
```

Common Types of Errors

- Numerical imprecision

```
def foo(n):
  counter, result = 0,0
  while counter != n:
    result += counter
    counter += 0.1
  return result

foo(5)
```

`counter` never exactly equals *n*

Common Types of Errors

- Logic

```
def fib(n):
  if n < 2:
    return n
  else:
    return fib(n-1) + fib(n-1)
```

How to debug?

- Think like a detective
  - Look at the clues: error messages, variable values.
  - Eliminate the impossible.
  - Run the program again with different inputs.
    - Does the same error occur again?

How to debug?

- Work backwards
  - From current sub-problem backwards in time
- Use a debugger
  - IDLE has a simple debugger
  - Overkill for our class
- Trace a function
- Display variable values

Displaying variables

```
debug_printing = True
def debug_print(msg):
  if debug_printing:
    print(msg)

def foo(n):
  counter, result = 0,0
  while(counter != n):
    debug_print(f'{counter}, {n}, {result}')
    counter, result = counter + 0.1, result + counter
  return result
```

Example

```
def fib(n):
  debug_print(f'n:{n}')
  if n < 2:
    return n
  else:
    return fib(n-1) + fib(n-1)
```

Other tips

- State assumptions clearly.

```
def factorial(n): # n integer >= 0
  if n == 0:
    return 1
  else:
    return n * factorial(n-1)
```

- Test each function before you proceed to the next.
  - Remember to test boundary cases

Summary

- Compound data helps us to reason at a higher conceptual level.
- Abstraction barriers separate usage of a compound data from its implementation.
- Only functions at the interface should be used.
- We can choose between different implementations as long as contract is fulfilled.

Summary

- Debugging often takes up more time than coding
- More an art than a science
- Play detective!
- Do it systematically
- Avoid debugging with good programming practices

Question of the Day

Implement a new Abstract Data Type (ADT) set with the following associated functions:

- `make_set()` – creates a new empty set object
- `add_set(set, object)` – adds an object to a set
- `remove_set(set, object)` – removes an object from a set
- `contains_set(set, object)` – returns `True` if the set contains the specified object